Measurement of the W boson helicity in top quark decay at DØ

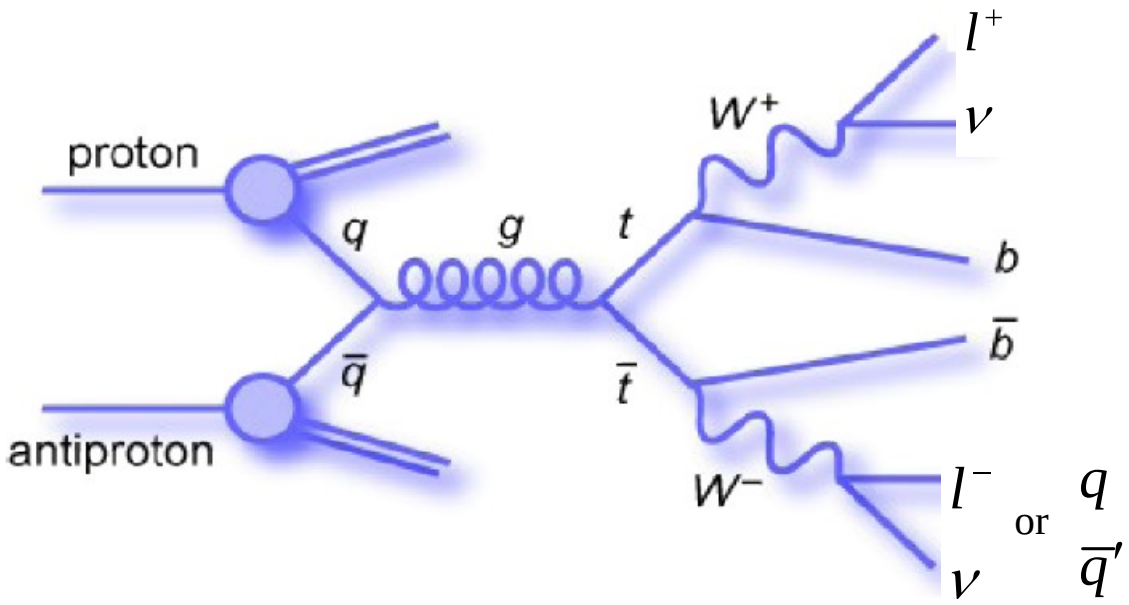
Bertrand Martin *(LPSC Grenoble)*

for the D0 collaboration

APS April meeting – 04/15/07

Outline

- Motivations
- Analysis guideline :
  - dilepton
  - lepton + jets
- Analysis technique :
  - cosθ* templates
- Results of f_+ measurement
  - Bayesian C.L.



Motivations

Standard Model :

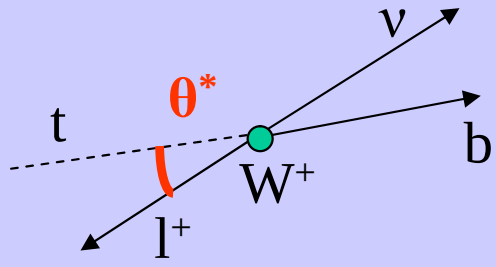
Due to the observed **Parity violation**, charged current (W boson) only couples left handed particles

V-A structure of the EW current in the S.M. Lagrangian

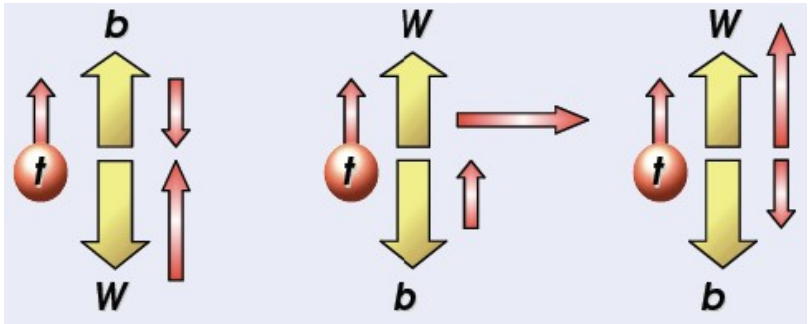
Physics observable sensitive to a possible **V+A** component : **W boson helicity**

Helicity is measured through the **cos(θ*) distribution**

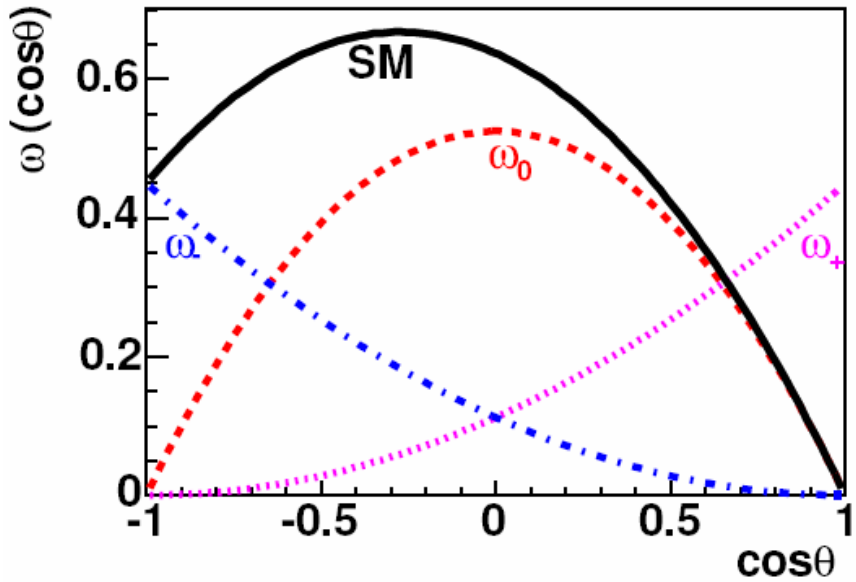
θ* : angle between the **top quark** flight direction and the **charged lepton momenta** in the **W rest frame** :



3 components in the cos(θ*) distribution : 3 helicity states



	Left handed	Longitudinal	Right handed
Fraction	$f_- \sim 0.30$	$f_0 \sim 0.70$	$f_+ \sim 1.4\ 10^{-3}$



A non zero f_+ could sign new physics…

Analysis guideline

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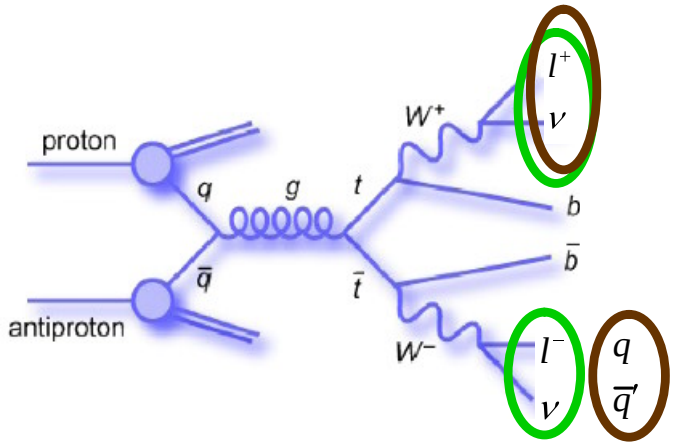
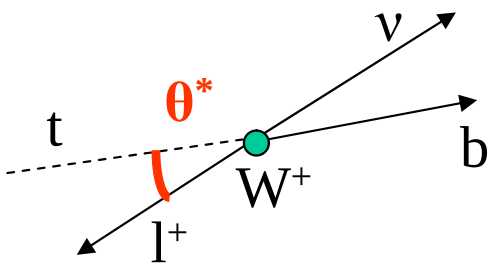
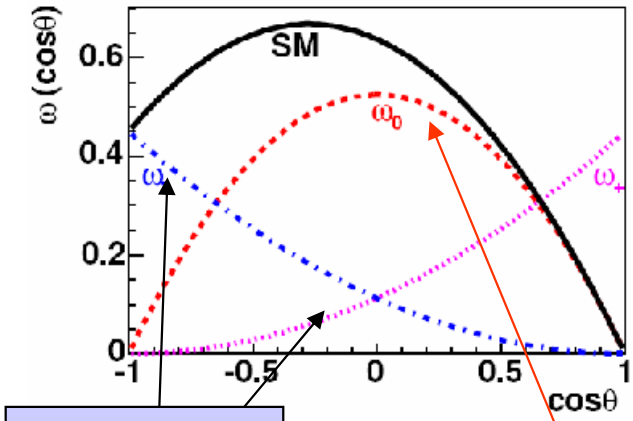






2 final states : **dilepton** **lepton+jets**

Measured

Fixed to SM value in the analysis

- Select a data sample enriched in ttbar candidate events

  (estimate physics and instrumental background contamination)

- For each selected event,
  - o reconstruct the top quark & W boson leptonic decay
  - o compute cos(θ*)
- Compare the cos(θ*) distribution obtained in data to different signal hypotheses :

MC ttbar samples with:
- **fixed f_0** (0.70)
- **different f_+** values

which one is the **most compatible with the observed data ?**

- Realize pseudo-experiments to estimate systematic uncertainties

Event selection

Dilepton (ee , eμ , μμ) :

Kinematics and topology

- 2 high p_T leptons (opposite charge)
- ≥ 2 high p_T jets
- M_{ll} outside the **Z** mass (ee, μμ)
- significant Missing E_T (2 υ)
- sphericity (ee) , H_T (eμ)

Main backgrounds :

- Drell-Yan : Z/γ* + jets
- Diboson (WW,WZ,ZZ)
- Fake lepton

Lepton (e, μ) + jets :

Multivariate selection

- Only 1 high p_T lepton
- ≥ 4 high p_T jets
- Missing E_T (1 υ)
- Likelihood discriminant

  (to suppress **W+jets**) **See next slide**

Main backgrounds :

- W + jets
- QCD multijet production

Likelihood discriminant (L_t) in l+jets

The variables used to discriminate signal (S) and background (B) must :

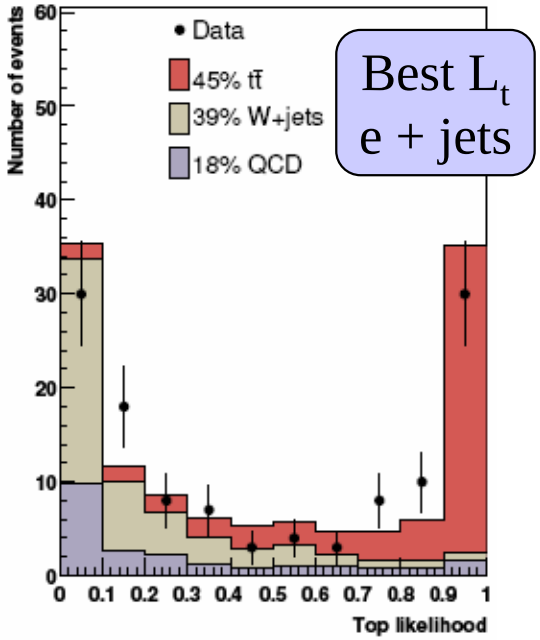
- be **well modeled** in the MC (K.S. proba > 5%)
- have **different shapes** between S and B

} 11 "good" variables (kinematics, b-tagging…)

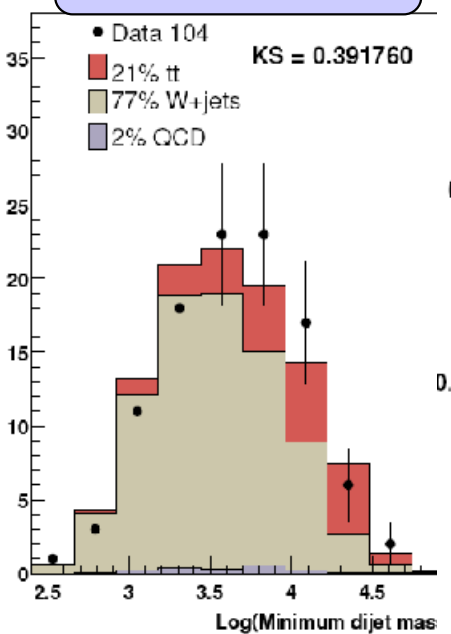
$$L_t \sim \frac{S}{S+B} \sim \frac{e^{\sum_{i}^{N\,\mathrm{var}} \ln\left(\frac{s}{b}\right)_i^{fit}}}{e^{\sum_{i}^{N\,\mathrm{var}} \ln\left(\frac{s}{b}\right)_i^{fit}} + 1}$$

Among 2^{11}-1 = 2047 possible L_t , the **best** one gives the **smallest error** on the measured $\mathbf{f_+}$

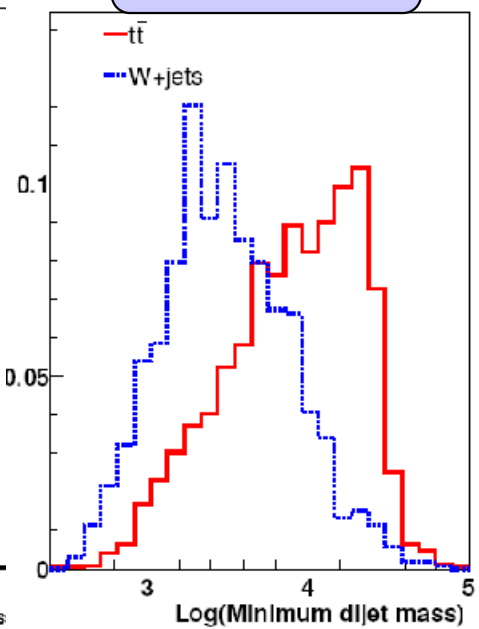
Best L_t e + jets



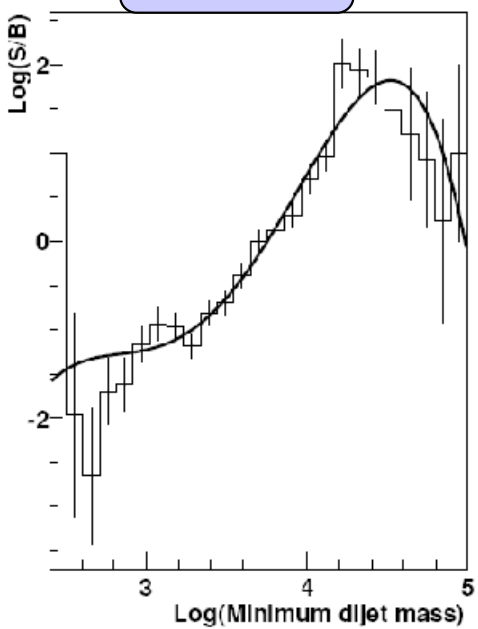
Good MC modeling



Discriminating ?



Fit ln(s/b)



Efficiency for best L_t

Source	μ+jets	e+jets
tt	0.72 ± 0.29	0.76 ± 0.15
$Wjjjj$	0.04 ± 0.004	0.07 ± 0.02
QCD	0.12 ± 0.17	0.10 ± 0.02

cos(θ*) templates

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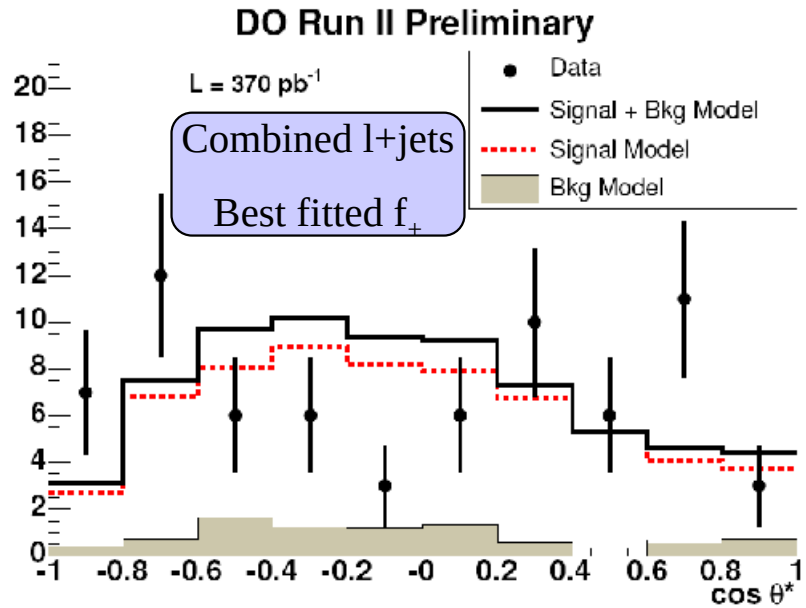
After final cuts (kinematics & topology for dilepton, L_t for l+jets), the **W leptonic decay**(s) have to be reconstructed :

- **l+jets** : 1 neutrino – kinematically constrained fit : **1 solution**
  - o HITFIT is used for the (lepton – b jet) pairing, assuming M_{top}=172.5 GeV
- **dilepton** : 2 neutrinos unknown momenta – **underconstrained**
  - o M_{top} assumption, algebraic resolution & **average** over the possible (lepton,jet) pairings
  - o Success in finding a solution : { 70 % ; 95 % if lepton and jet **energies are smeared**

The **cos(θ*) distribution** is built for :

- Data
- Signal for different f_+ (V-A / V+A)
- Background

Likelihood maximization : find **which f_+** value **best reproduces the data distribution**



Results with 370 pb^{-1}

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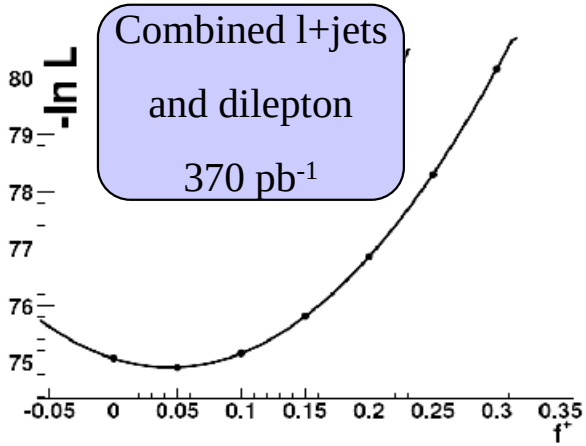

$$f_+^{l+jets} = 0.11 \pm 0.09\,(stat)$$

$$f_+^{dilepton} = -0.09 \pm 0.15\,(stat)$$

The likelihood maximization does not guarantee $f_+ > 0$!

$$f_+^{comb} = 0.056 \pm 0.080\,(stat)$$

Bayesian confidence level (CL %) : use a prior probability density

- flat for $f_+ \in [0\ ,\ 0.30]$ and **null in the non-physical region**

Confidence interval $[x_{min}\ ,\ x_{max}]$ based on the **likelihood integral**, such that :

Max. likelihood — Likelihood function

$$\frac{\int_{x_{min}}^{x_{ML}} L(x)dx}{\int_{0}^{0.30} L(x)dx} = \frac{CL}{2} = \frac{\int_{x_{ML}}^{x_{max}} L(x)dx}{\int_{0}^{0.30} L(x)dx}$$

@ 95% of confidence level :

$$0 < f_+^{l+jets} < 0.264$$

$$0 < f_+^{dilepton} < 0.239$$

$$0 < f_+^{comb} < 0.226$$

Summary

With 370 pb^{-1} of analyzed data, the combined lepton+jets and dilepton measurements of the right handed W fraction f_+ is :

(assuming $f_0 = 0.70$)

$$f_+ = 0.056 \pm 0.080\,(\text{stat}) \pm 0.057\,(\text{syst})$$

$$f_+ < 0.226 \ @95\%\text{C.L.}$$

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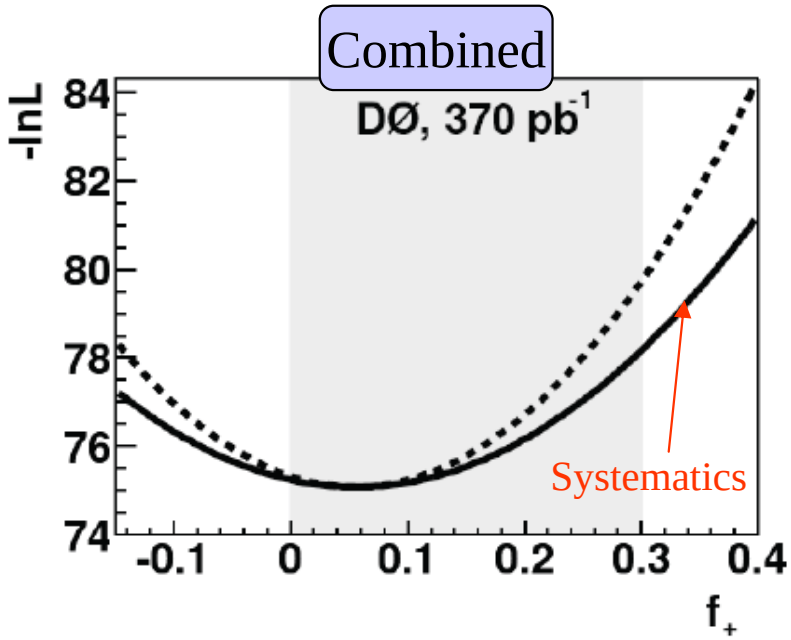


This measurement is compatible with the predicted Standard Model value :

$f_+ = 1.36 \times 10^{-3}$

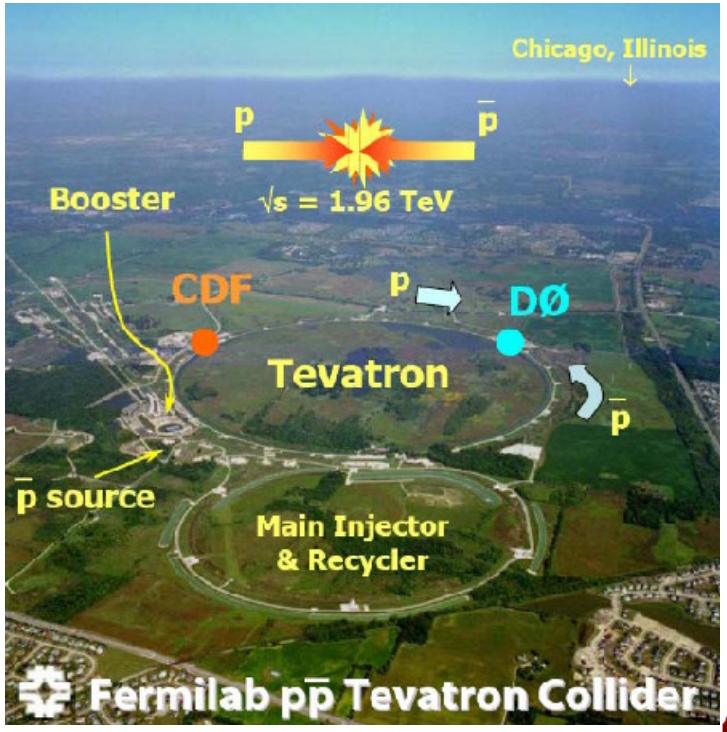
The analysis is currently updated with an integrated luminosity of ~ 1 fb^{-1}

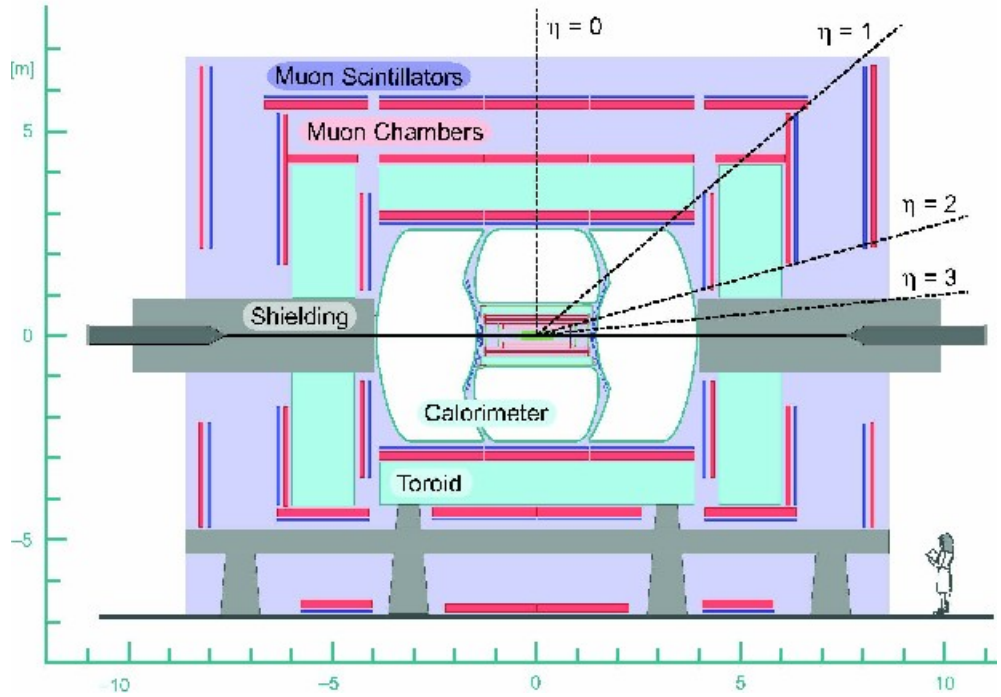
The CDF preliminary results for lepton + jets with ~ 1fb^{-1} are :

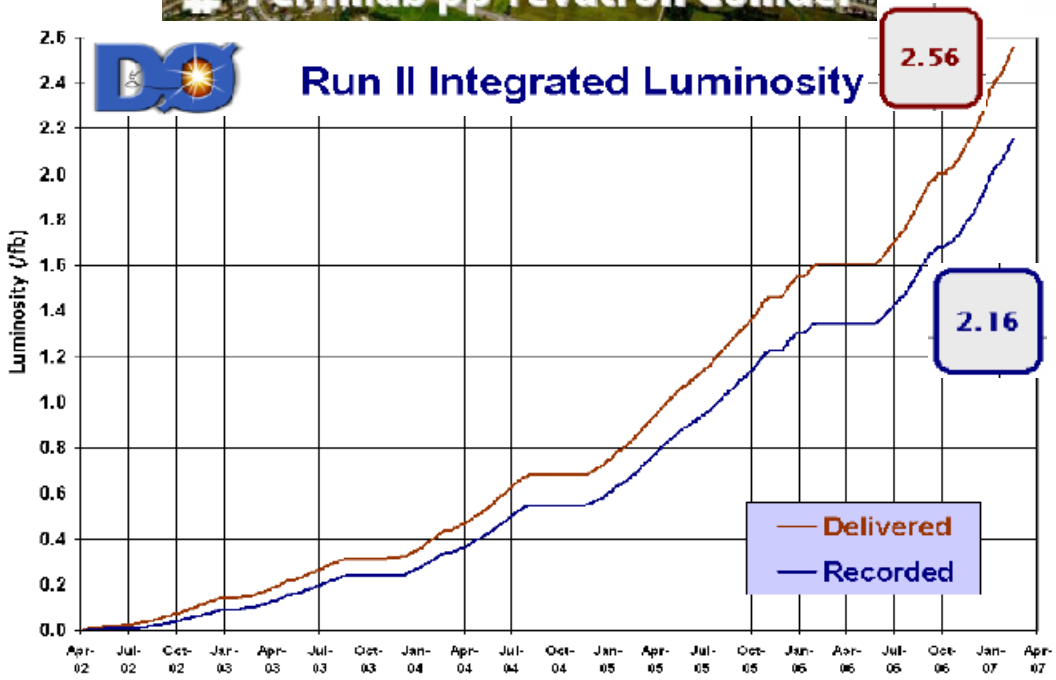
- $f_+ = -0.03 \pm 0.06\,(stat)\,^{+0.04}_{-0.03}\,(syst)$ assuming $f_0 = 0.70$ ($f_+ < 0.10$ @ 95% C.L.)
- $f_0 = 0.59 \pm 0.12\,(stat)\,^{+0.07}_{-0.06}\,(syst)$ assuming $f_+ = 0$

Backup slides

The DO experiment







Results on the W helicity will be shown for 370 pb^{-1} of analyzed data, while D0 has more than 2 fb^{-1} on tape

f_+ measurement

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Likelihood maximization (w.r.t. n_s and $n_{b,i}$) :

Gaussian term for the **background normalization**

How well does this f_+ hypothesis match with the cosθ* data distribution

$$L(f_+) = \prod_{i=1}^{N_{bkg}} e^{\frac{(n_{b,i} - \bar{n}_{b,i})^2}{2\sigma_{b,i}^2}} \times \prod_{j=1}^{N_{bins}} P(d_j; n_j)$$

Observed data

Predicted average

$\bar{n}_{b,i}$ and $\sigma_{b,i}$ obtained after final selection :

- kinematics & topo : dilepton
- L_t discriminant cut : lepton + jets

Poissonian probability to observe in the **bin j** :

d_j data events with a predicted **average** of

$$n_j(f_+) = n_s(f_+) + \sum_{i=1}^{N_{bkg}} n_{b,i}$$

Ensemble tests

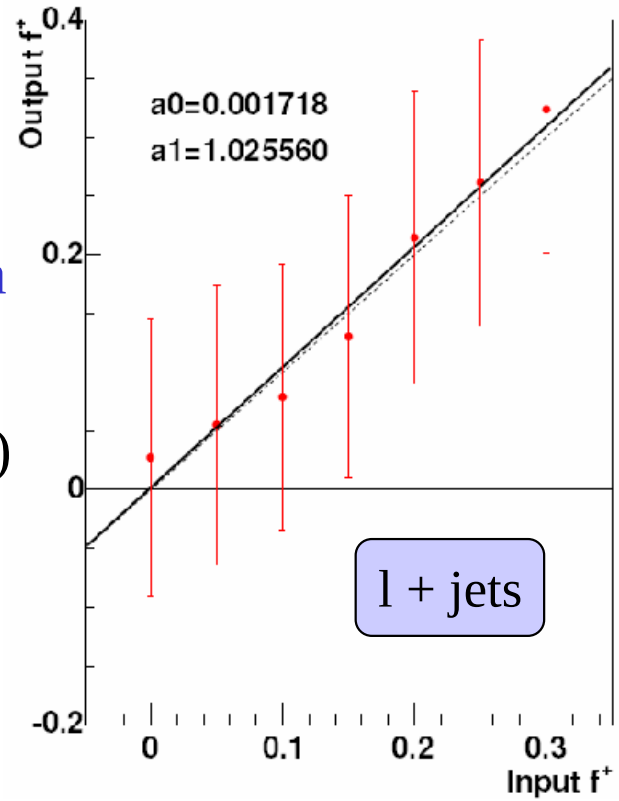
Test of the maximum likelihood performance

Create a "pseudo-dataset" of MC events with :

- the same number of MC events as observed in the data
- the signal/background composition can fluctuate according to a binomial distribution ($n_{bkg} = N_{tot}^{observed} - n_s$)

Compare the fitted f_+ to the known input f_+

Repeat the procedure 1000 times for each f_+ value



Evaluation of systematic uncertainties

o Varying parameters can affect both the data sample composition (different selection efficiency of the likelihood discriminant) and the shape of cos(θ*) distributions.

o Effect on the fitted f_+ : studied with pseudo-experiments
(varying the parameters in the peudo-dataset)

o Source : Jet Energy Scale, M_{top} , MC statistics, heavy flavor content (W+jets), …

$\Delta f_+ \sim 0.03$ to 0.04 (for each one)